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INVESTIGATION OF THE INFLUENCE OF VORTEX GENERATORS ON TURBULENT BOUNDARY LAYER SEPARATION

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16. Abstract The influence of a parallel system and a diffusor-type system of vortex generators on the position of the shock waves on the airfoil profile is studied experimentally. Data showing the superiority of a parallel system of vortex generators mounted at an angle of 20° to the oncoming flow over a system of diffusers mounted pairwise on the airfoil are presented.

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INVESTIGATION OF THE INFLUENCE OF VORTEX GENERATORS ON TURBULENT BOUNDARY LAYER SEPARATION

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The prevention or mitigation of a number of undesirable phenomena occurring in flight vehicles in transonic flow conditions connected with the separation of the boundary layer from the shock wave is of great practical importance. /22*

One means of controlling the boundary layer at points where the flow is separated are vortex generators. These are special devices on the surface of the flight vehicle for increasing the momentum transfer between the outer part of the boundary layer and the part near the wall. For example, small plates which are perpendicular to the surface, whose height is on the order of the boundary layer thickness, can be used as vortex generators. Vortices which run out from the lateral edges of the plates (with a rectangular, trapezoidal or triangular profile), attached to the surface at a certain angle of attack, increase the energy of the flow in the immediate vicinity of the wall. When the geometric parameters of the vortex generators and their location on the surface are properly selected, the separation of the boundary layer which occurs at an adverse pressure gradient can be displaced rearward along the flow, or, in some cases, eliminated completely. The results of studies of vortex generators of this type are given in articles [1] and [2].

This article experimentally investigates the prevention of turbulent boundary layer separation at transonic velocities on an airfoil half section with the aid of vortex generators. The experiments were carried out in a wind tunnel in the Mach number

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* Numbers in the margin indicate pagination in the foreign text.

range M = 0.6-1. The model was an airfoil half section of relative thickness $\bar{c}$ = 10% with a chord b = 150 mm. The contour of the airfoil half section had the shape of an arc of a circle with radius R = 195 mm. To obtain a sufficiently thick turbulent boundary layer on the surface of the airfoil half section, the model was mounted on the wall in the test section of the wind tunnel. A thin boundary layer is obtained during tests of models located in the center of the flow, which makes the geometric modeling of vortex generators in relation to the height of the boundary layer difficult. The airfoil half section was tested with the aim of obtaining the pattern of the effect of vortex generators on the separation rather than quantitative characteristics for a particular concrete profile. /23

Plates with a rectangular outline protruding approximately 4 mm above the surface of the airfoil half section were used as the vortex generators. The experiments were conducted using two arrangement schemes for the vortex generators along the span of the model -- a parallel and a diffuser scheme (Fig. 1).

In the parallel scheme, the vortex generators were mounted along the span of the model at equal distances t = 12.5 mm at an angle of attack to the incident flow β = 20°, at a relative distance $\bar{x}_r$ = X/b = 0.5 and 0.63 from the leading edge. Vortex generators with a b = 10 and 20 mm chord were used.

In the diffuser scheme, the vortex generators were mounted pairwise along the span at equal distances t_1 = 40 mm (t_2 = 10 mm) at an angle β = ±15° to the incident flow, at a relative distance $\bar{x}_r$ = 0.67 from the leading edge of the model. In this spacing system, the chord of the vortex generators was 5 and 10 mm. The center section in the tail part of the model had vents for the measurement of pressure. The oil-film method, measurement of the pressure distribution and optical methods (shadowgraph method, Tepler method) were used to record the results of the experiment. /24

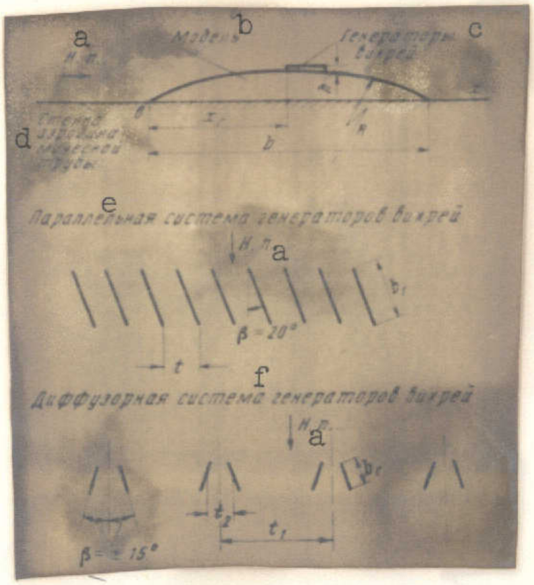

Fig. 1.

Key: a. Incident flow; b. model; c. vortex generators; d. wind tunnel wall; e. parallel system of vortex generators; f. diffuser system of vortex generators

An indispensable condition for the efficiency of the vortex generators under consideration is their spacing within a zone on the order of the boundary layer thickness δ. Measurements of the velocity profile on the wall of the wind tunnel directly in front of the model and decoded data from the optical studies have shown that the selected height of the vortex generators approximately satisfies the conditions for their highest efficiency at $h \sim \delta$.

As the local supersonic zone is formed during flow about the model, the vortex generators change both the dimensions of the boundary layer separation region, displacing it from under the shock wave, and the position of the shock wave itself. This can be seen in Fig. 2, where, as an example, we present the results obtained from making the flow pattern about the airfoil half section, obtained at Mach number $M_\infty = 0.93$ by different methods, visible. /25

With the parallel system of vortex generators, only small local separation zones are visible near the shock wave, instead of a wide boundary layer separation region. The shock is displaced toward the trailing edge of the airfoil half section. The diagram for the pressure on the airfoil half section changes due to the boundary layer separation that was prevented.

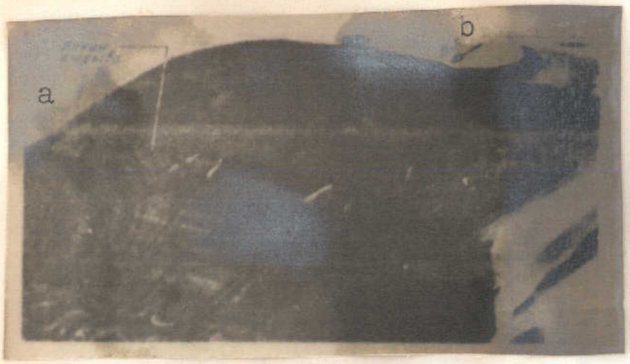

Fig. 2a.

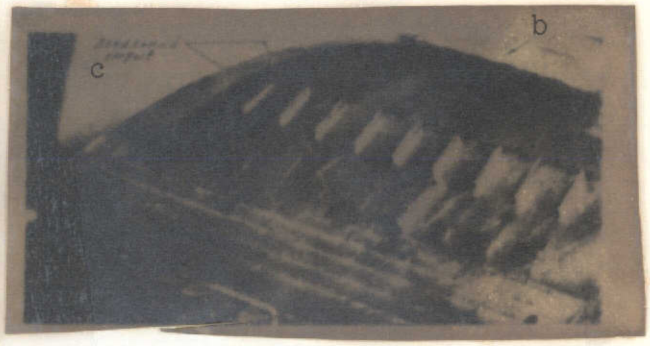

Fig. 2b

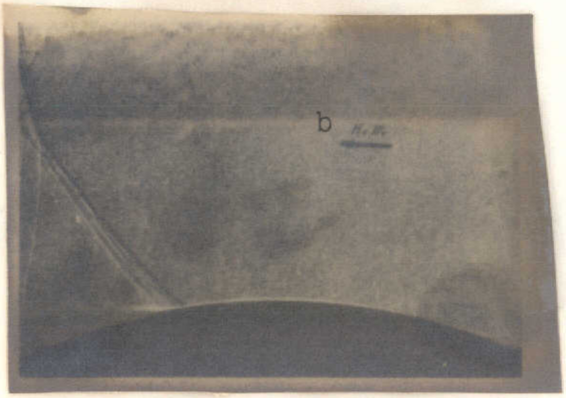

Fig. 2c.

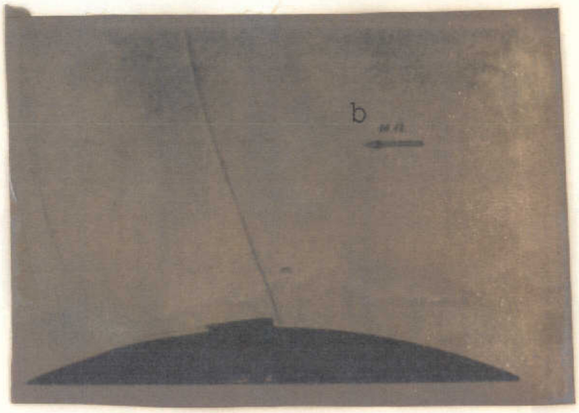

Fig. 2d.

Key: a. Separation line
b. Incident flow
c. Local separation

On the basis of a comparison of the pressure distributions on the model without the vortex generators and the parallel system of vortex generators (Fig. 3), one can conclude that in the given case the vortex generators (b_r = 20 mm) produce flow about the model with practically no separation. A diagram in which the /26 pressure is gradually recovered is obtained instead of a diagram with a constant pressure region.

Unlike the parallel system, the diffuser system of vortex generators only partially and nonuniformly prevents the boundary layer separation along the span of the airfoil half section.

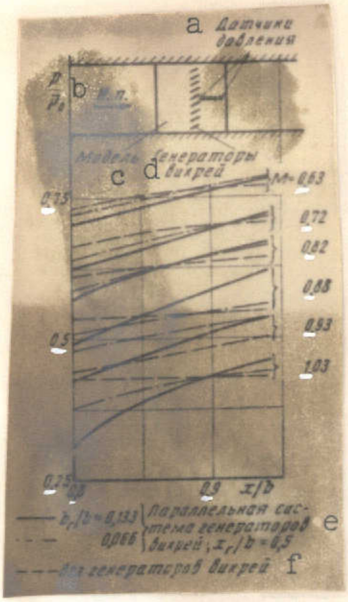

Fig. 3.

Key: a. Pressure sensor; b. Incident flow; c. Model; d. Vortex generators; e. Parallel system of vortex generators, $x_r/b = 0.5$; f. Without vortex generators

In subcritical flow conditions, when the local velocities are lower than the velocity of sound, the mounting of the parallel vortex generator system almost completely eliminates boundary layer separation in the tail part of the airfoil half section. This is confirmed not only by the oil-film flow pattern, but also by the changes in the pressure diagram (see Fig. 3). In the case of the diffuser vortex generator system (with the geometric parameters used in this article) and also in the case of boundary layer separation displaced from under the pressure wave, the separation is only partially prevented. The nonuniform effect of the diffuser vortex generator system along the span for all practical purposes did not change the pressure distribution in the center section of the model when the vortex generators were mounted. Thus, the diffuser system studied turned out to be much less efficient than the parallel system, which of course does not preclude further studies on the selection of the diffuser system parameters.

The points at which the generators were mounted and the length of the generator chord were varied in the experimental studies with the parallel spacing of the vortex generators. The displacement of the vortex generators along the chord in the range $\overline{x}_r = 0.5\text{-}0.63$ had practically no effect on their efficiency in the entire range of Mach numbers M_∞ studied. On the other hand, a change in the generator chord dimension does have an effect on the vortex strength of the system and consequently on its effect on

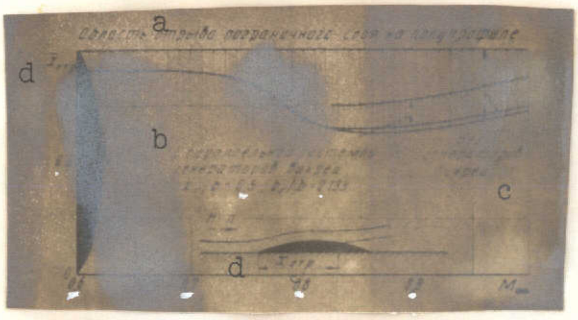

Fig. 4.

Key: a. Boundary layer separation region on airfoil half section; b. With parallel system of vortex generators; c. Without vortex generators; c. $\overline{x}_{sep}$

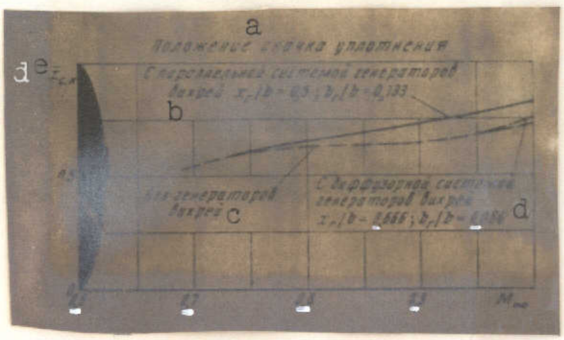

Fig. 5.

Key: a. Position of shock wave; b. With parallel system of vortex generators; c. Without vortex generators; d. With diffuser system of vortex generators; d. $\overline{x}_{shock}$

the boundary layer. The change from a b_r = 20 mm vortex generator chord to a b_r = 10 mm chord considerably reduced the effect of vortex generators on the boundary layer separation.

Figs. 4 and 5 give the position of the separation zone and the shock wave which depend on the Mach number M_∞ of the incident flow for the model with vortex generators. The same figures show analogous curves for the model without vortex generators. When the experimental material was processed, the mean value $\overline{x}_{sep}$ along the chord, obtained from photographs of the spreading oil film, was taken as the position of the point where the boundary layer separates, and the position of the shock wave was determined from photographs of the flow about the model obtained using optical methods.

The graph of $\overline{x}_{sep}(M_\infty)$ for an /27
airfoil half section without vortex generators describes a well-known law: the separation in the tail part of the model ($\overline{x}_{sep}$ = 0.9) propagates forward as the velocity of the incident flow increases, attaining, in the given case at M = 0.85, a position corresponding to $\overline{x}_{sep}$ = 0.63. This is explained by the fact that during the transition to supercritical flow, the

separation of the boundary layer caused by the adverse pressure gradient in the tail part of the airfoil half section changes into separation from under the shock wave. On the model with the parallel system of vortex generators, the separation is practically eliminated during subcritical flow, and during supercritical flow, it is reduced at $M_\infty > 0.82$ to local separation of length on the order of 0.16.

Due to the prevented separation, the flow about the airfoil half section is restored, and the associated displacement of the shock wave to the trailing edge takes place. The displacement varies, and it depends on the Mach numbers M. In the Mach number range M_∞ ($M_{cr} < M_\infty < 0.75$-0.80), when the separation occurs near the trailing edge of the airfoil half section in the presence of a shock, i.e., not in the shock region, vortex generators which prevent separation have little effect on the position of the shock wave. The vortex generator mounting has a considerable effect on the position of the shock wave during the separation of the boundary layer displaced from under the shock wave. Thus, at Mach numbers $M_\infty = 0.8$-1, the parallel system of vortex generators displaces the shock wave toward the trailing edge by approximately 10% of the chord of the airfoil half section. /28

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